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MEASUREMENT OF CHARMED MESON LIFETIMES WITH BELLE

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The lifetimes of charmed mesons have been measured using 2.75 fb^{-1} of data collected with the Belle detector at KEKB. Each candidate is fully reconstructed to identify the flavor of the charmed meson. The lifetimes are measured to be $\tau(D^0) = (414.8 \pm 3.8 \pm 3.4)$ fs, $\tau(D^+) = (1040^{+23}_{-22} \pm 18)$ fs and $\tau(D_s^+) = (479^{+17}_{-16}{}^{+6}_{-8})$ fs, where the first error is statistical and the second error is systematic. The ratios of the lifetimes of D^+ and D_s^+ with respect to D^0 are measured to be $\tau(D^+)/\tau(D^0) = 2.51 \pm 0.06 \pm 0.04$ and $\tau(D_s^+)/\tau(D^0) = 1.15 \pm 0.04^{+0.01}_{-0.02}$. The mixing parameter y_{CP} is also measured through the lifetime difference of D^0 mesons decaying into CP-mixed states and CP eigenstates. We find $y_{CP} = (1.0^{+3.8}_{-3.5}{}^{+1.1}_{-2.1})$ %, corresponding to a 95% confidence interval $-7.0\% < y_{CP} < 8.7\%$. All results are preliminary.

Measurements of individual charmed meson lifetimes provide useful information for the theoretical understanding of the heavy flavor decay mechanisms[1,2]. Moreover, the $D^0\overline{D}^0$ mixing parameters, $y \equiv (\Gamma_H - \Gamma_L)/(\Gamma_H + \Gamma_L)$ and $x \equiv 2(M_H - M_L)/(\Gamma_H + \Gamma_L)$, can be explored by measuring the lifetime difference of the D^0 meson decaying into a CP-mixed state $D^0 \to K^-\pi^+$ and a CP-eigenstate $D^0 \to K^-K^+$. The parameter y_{CP}, defined by $y_{CP} \equiv \frac{\Gamma(\mathrm{CP\ even})-\Gamma(\mathrm{CP\ odd})}{\Gamma(\mathrm{CP\ even})+\Gamma(\mathrm{CP\ odd})} = \frac{\tau(D^0\to K^-\pi^+)}{\tau(D^0\to K^-K^+)} - 1$, is related to y and x by the expression $y_{CP} = y\cos\phi - \frac{A_{mix}}{2} x \sin\phi$, where ϕ is a CP violating weak phase due to the interference of decays with and without mixing, and A_{mix} is related to CP violation in mixing. E791[3,4] and FOCUS[5] have measured $y_{CP} = (0.8 \pm 2.9 \pm 1.0)\%$ and $y_{CP} = (3.42 \pm 1.39 \pm 0.74)\%$ respectively. It is interesting that the FOCUS result is non-zero by more than two standard deviations. On the other hand, CLEO[6] gives results for $D^0\overline{D}^0$ mixing through $D^0 \to K^+\pi^-$, $y'\cos\phi = (-2.5^{+1.4}_{-1.6})\%$, $x' = (0.0 \pm 1.5 \pm 0.2)\%$ and $A_{mix} = 0.23^{+0.63}_{-0.80}$, where $y' = y\cos\delta - x\sin\delta$ and $x' = x\cos\delta + y\sin\delta$; the parameter δ is the strong phase between the doubly Cabibbo suppressed decay $D^0 \to K^+\pi^-$ and the Cabibbo allowed decay $\overline{D}^0 \to K^+\pi^-$ ($\delta = 0$ in the $SU(3)$ limit). The FOCUS and CLEO results could be consistent if there is a large $SU(3)$ breaking effect in $D^0 \to K^\pm\pi^\mp$ decays[7].

In the lifetime measurements[8], D^0, D^+ and D_s^+ mesons are fully reconstructed via the decay chains[a], $D^0 \to K^-\pi^+$, $D^0 \to K^-K^+$, $D^+ \to K^-\pi^+\pi^+$ (with $D^{*+} \to D^+\pi^0$ requirement), $D^+ \to \phi\pi^+$, $\phi \to K^+K^-$, $D_s^+ \to \phi\pi^+$, and $D_s^+ \to \overline{K}^{*0}K^+$, $\overline{K}^{*0} \to K^-\pi^+$.

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[a] Charge-conjugate modes are implied throughout this paper.

The decay vertex($\boldsymbol{x}_{dec}$) of the charmed meson is determined and then the production vertex($\boldsymbol{x}_{pro}$) is obtained by extrapolating the D flight path to the interaction region of e^+e^-. The projected decay length(L) and the proper-time(t) are obtained from $L = (\boldsymbol{x}_{pro} - \boldsymbol{x}_{dec}) \cdot \boldsymbol{p}_D/|\boldsymbol{p}_D|$ and $t = Lm_D/c|\boldsymbol{p}_D|$ respectively, where $\boldsymbol{p}_D$ and m_D are momentum and mass of the charmed meson.

An unbinned maximum likelihood fit is performed to extract the lifetimes. The probability density function(P) for each event consists of a signal term and the two background terms, representing components of the background with non-zero lifetime and zero lifetime respectively. The likelihood function(L) is then given by

$$\begin{aligned} L = \prod_i P(t^i, \sigma_t^i, f_{SIG}^i) &= \prod_i [f_{SIG}^i \int_0^\infty dt' \frac{1}{\tau_{SIG}} e^{\frac{-t'}{\tau_{SIG}}} R_{SIG}(t^i - t', \sigma_t^i) \\ &+ (1 - f_{SIG}^i) \int_0^\infty dt' \{ f_{\tau_{BG}} \frac{1}{\tau_{BG}} e^{\frac{-t'}{\tau_{BG}}} \\ &+ (1 - f_{\tau_{BG}}) \delta(t') \} R_{BG}(t^i - t', \sigma_t^i)], \end{aligned}$$

where f_{SIG}^i and $f_{\tau_{BG}}$ are fractions for the signal and the background with lifetime, τ_{SIG} and τ_{BG} are the signal and background lifetimes, R_{SIG} and R_{BG} are the resolution functions for the signal and the background, and t^i, σ_t^i are the measured proper-time, and its error, for each event. The fraction f_{SIG}^i is obtained based on the charmed meson mass for each event. The resolution functions R_{SIG} and R_{BG} are represented using

$$R(t, \sigma_t) = (1 - f_{tail}) \frac{1}{\sqrt{2\pi} S \sigma_t} e^{-\frac{t^2}{2S^2\sigma_t^2}} + f_{tail} \frac{1}{\sqrt{2\pi} S_{tail} \sigma_t} e^{-\frac{t^2}{2S_{tail}^2 \sigma_t^2}},$$

where S and S_{tail} are global scaling factors for the estimated error σ_t for the main and tail Gaussian distributions and f_{tail} is a fraction of the tail part. Fig.1 shows the proper-time distributions and fit results for $D^0 \to K^-\pi^+$ and $D_s^+ \to \phi\pi^+$.

Table 1. Comparison of our results with PDG99[9] world average and previous measurements.

	$\tau(D^0)$ fs	$\tau(D^+)$ fs	$\tau(D_s^+)$ fs	y_{CP} %
PDG99	415 ± 4	1057 ± 15	495 ± 13	–
E791	$413 \pm 3 \pm 4$	–	$(518 \pm 14 \pm 7)^\dagger$	$0.8 \pm 2.9 \pm 1.0$
CLEO	$408.5 \pm 4.1^{+3.5}_{-3.4}$	$1034 \pm 22^{+10}_{-13}$	$486 \pm 15 \pm 5$	–
FOCUS	$409.2 \pm 1.3^\ddagger$	–	$506 \pm 8^\ddagger$	$3.42 \pm 1.39 \pm 0.74$
Belle	$414.8 \pm 3.8 \pm 3.4$	$1040^{+23}_{-22} \pm 18$	479^{+17+6}_{-16-8}	$1.0^{+3.8+1.1}_{-3.5-2.1}$

†This result is included in the PDG99 world average. ‡No systematic error is given.

We measure the D^0 meson lifetime to be $\tau(D^0) = (414.8 \pm 3.8 \pm 3.4)$ fs using the decay mode $D^0 \to K^-\pi^+$. The D^+ meson lifetime is measured to be (1049^{+25+16}_{-24-19}) fs for the $D^+ \to K^-\pi^+\pi^+$ decay sample and (974^{+68+26}_{-62-18}) fs for the $D^+ \to \phi\pi^+$ decay sample. The D_s^+ meson lifetime is measured to be $(470 \pm 19^{+5}_{-7})$ fs for the $D_s^+ \to \phi\pi^+$ decay sample and (505^{+34+8}_{-33-12}) fs for the $D_s^+ \to \overline{K}^{*0}K^+$ decay sample. Table 1 summarizes our combined measurement results with previous measurements and

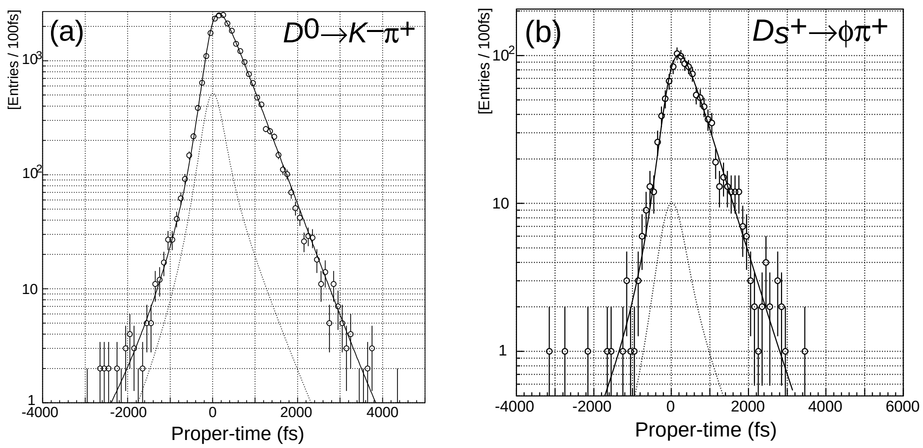

Fig. 1. The proper-time distributions and fit results for $D^0 \to K^-\pi^+$ and $D_s^+ \to \phi\pi^+$. The dotted curve represents the background.

the world average. The main sources of our systematic errors are uncertainties in the resolution function, the proper-time dependence of the reconstruction efficiency and a bias in the reconstruction of the decay vertex. The ratios of the lifetimes of D^+ and D_s^+ with respect to D^0 are measured to be $\tau(D^+)/\tau(D^0) = 2.51 \pm 0.06 \pm 0.04$ and $\tau(D_s^+)/\tau(D^0) = 1.15 \pm 0.04^{+0.01}_{-0.02}$. The mixing parameter y_{CP} is also measured through the lifetime difference of D^0 mesons decaying into CP-mixed states and CP eigenstates. We find $y_{CP} = (1.0^{+3.8}_{-3.5}{}^{+1.1}_{-2.1})$ %, corresponding to a 95% confidence interval $-7.0\% < y_{CP} < 8.7\%$.

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